OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 11, November 2010, p. 1752 - 1755

Effect of Sn on the microstructure and wearing capacity of Ti-10Zr-5Mo-xSn alloys

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The Ti-10Zr-5Mo-xSn alloys were molten in the non-consumable electric arc furnace. Influences of Sn on the phases, microstructures and correlative mechanical properties of Ti alloys have been analyzed by use of X ray diffractive instrument(DX2000-), optical microscope (4XC-) for metallography, sclerometer (HV-50A) and machine for abrasion(M-200). It was found that Ti-10Zr-5Mo-xSn alloys were composed of equiaxed α phase. Moreover, with the increase of Sn, diffractive peak of α″ phase began to appear and peak intensity increased gradually, and Sn could stabilize β together with Mo during annealing process. Furthermore, the addition of Sn could improve the hardness (HV) and abrasion resistance.

(Received August 20, 2010; accepted November 10, 2010)

Keywords: Titanium Alloy, Sn, Microstructure, Microhardness, Abrasion resistance

1. Introduction

Due to their light weight, excellent corrosion resistance, biocompatibility and mechanical properties, pure titanium and its alloys have been widely used for many biomedical applications. For example, they are used for dental crowns and bridges, dental implants and plates for oral maxillofacial surgery [1-2]. The Ti-6Al-4V alloy has been put forward as a possible replacement for commercially pure titanium because of its higher strength and better corrosion resistance. However, the release of Al and V element from the alloy might cause some long-term health problems [3-4]. Therefore, the research of new Ti alloys is important for biomedical applications. The new Ti alloy without Al or V is supposed to have good mechanical properties and biocompatibility. Medical β titanium alloys just meet these requirements, so it is being developed rapidly.

It is well known that the properties of Ti alloys depend on their phases and crystal structures, and certain phases may be stabilized by the addition of alloying elements. Thus, the mechanical properties of titanium might be enhanced through alloying. When dissolved in Ti, Zr, as a neutral element, has high solubility in both α Ti and β Ti. Zr can enhance strength and improve the plasticity of alloys, and also guarantee fine processing properties [5-6]. In our previous research, a Ti–10Zr alloy has been developed, and it has higher hardness and better abrasion resistance than pure titanium [7]. However, its strength and elastic modulus were not sufficient for clinical dental applications. So the β- isomorphous element Mo and the neutral element Sn were added to the Ti-10Zr alloy in this experiment. These Ti-10Zr-5Mo-XSn alloys were considered to be suitable for biomaterials since they do not contain elements such as Al or V.

2. Experimental procedures

2.1 Alloy smelting and heat treatment

Alloying elements selected to add to the spongy titanium for the study included Zr, Mo, and Sn, which were all 99.9% pure, as shown in Table 1. The alloys were molten in the non-consumable electric arc furnace. The melting chamber was first evacuated and purged with argon. Appropriate amounts of each metal were molten in a copper hearth. The cast alloys were heated up to 900□, keeping the temperature for two hours, and then cooled in the furnace.

Table 1.Chemical composition of alloys.

Samples chemical composition (w%)			
	Zr	Mo	Sn
1#	10	5	3
2#	10	5	4
3#	10	5	5

2.2 Experimental procedures

The alloys were cut to 10 mm×10 mm×10 mm by the linear cutting machine. The phase and structure of the alloys were evaluated by means of an X-ray diffraction (DX2600) for phase analysis and optical microscope (4XC-) for microstructure of the etched alloys. The microhardness of polished alloys was measured by using the microhardness sclerometer (HV-50A).

The abrasion resistance of alloys was studied by use of the M-200 machine for abrasion at 10N with the artificial saliva as the lubricant. The grinding test of each alloy was performed for an hour at the same grinding speed, and a new wheel was applied for each sample. The weight of alloys worn (mg) per 10 min was weighed by

the electronic balance. The worn surfaces of the alloys were then observed by using optical microscopy. Abrasion resistance was evaluated from the total weight loss of each alloy removed for an hour. The artificial saliva in this study was confected, according to international standard GB/T1886-2002 [8].

3 Results and discussion

3.1 Phase

As shown in Fig. 1, according to the JCPDS files 44-1294(α-Ti) and 44-1288(β-Ti) [9-10], Ti-10Zr-5Mo-XSn alloys were mainly composed of α and β phase. With increase of Sn, characteristic peaks of α″ phase appeared in the host, and intensity enhanced gradually.

Fig. 2 indicated that Ti-10Zr-5Mo-XSn alloys after annealing were mainly composed of α phase all the same. With increase of Sn, intensity of β phase increased, while intensity of α phase decreased gradually. In other words, proportion of β phase increased. It was thought that β isomorphous element Mo made a portion of β phase stabilize, thus could be retained up to room temperature. Furthermore, when neutral element Sn was added to Ti alloy solely, it hardly influenced β transformation temperature of Ti. However, while Sn was added to Ti alloy with β isomorphous element Mo, Sn could stabilize β phase together with Mo during annealing process.

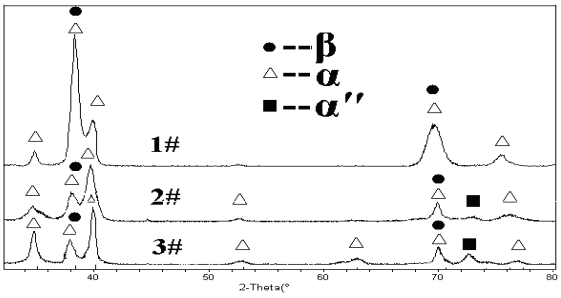

Fig. 1. X-ray diffraction spectrum of the as-cast alloys.

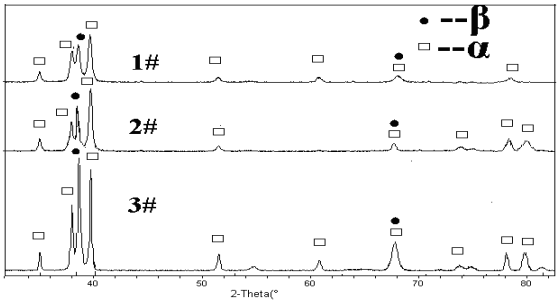

Fig. 2. X-ray diffraction spectrum of alloys after annealing.

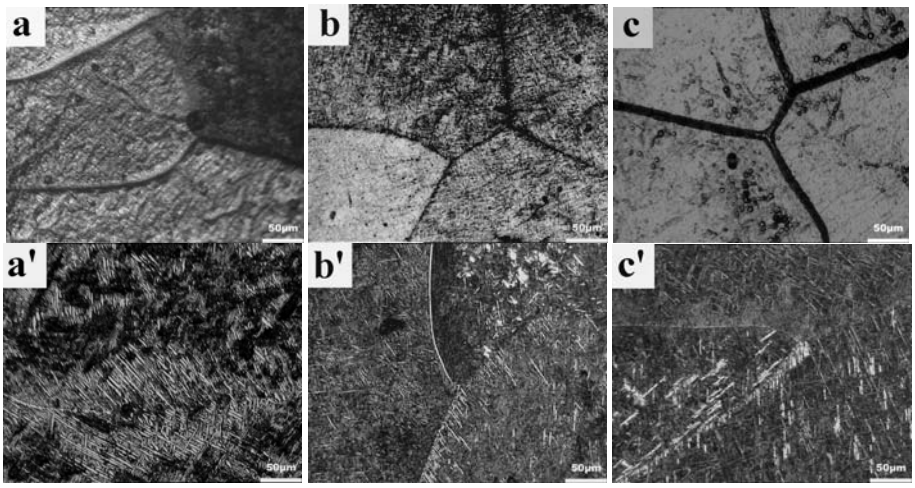

Fig. 3. Optical microstructure of Ti-10Zr-5Mo-xSn alloys (a,b,c, before annealing ; a',b',c', after annealing).

3.2 Microstructure

Fig. 3 showed that the as-cast alloys were composed of equiaxed α phase. At the same time, some substructures and a few dispersed phases existed within crystal grains. 1# alloy with 3% Sn(Fig. 3a) had obvious substructures, and the grain boundary of metastructures could be clearly observed. 2# alloy with 4% Sn (Fig. 3b) had blurry substructures and a few dispersed phases appeared. Optical microstructure of 3# alloy with 5% Sn(Fig. 3c) demonstrated that substructures disappeared, but dispersed network phases was more and clearer. Therefore, along with increase of Sn, metastructures of the as-cast Ti alloys disappeared gradually, but dispersed phases gradually increased.

As shown in Fig. 3(a′,b′,c′), after annealing, many needle-like or flaky α phase lined up in parallel within the local area of the original β crystal grains, with different lengths. β-grain boundary was destroyed by these different orientation α phases. β phase, with a lamella or a single

aggregation point, discontinuously distributed at the borders of needle-like α phase. It was thought that α phase crystal nucleuses came into being firstly at the β grain boundaries during annealing process. Owing to preferred orientation, α phase crystal grains at the borders grew up with needle-like, toward the interior of β crystal grains, so that β grain boundaries were destroyed. Fig. 3 (a′,b′,c′) indicated that more β phase lamellas remained along with increase of Sn.

3.3 Microhardness

Fig. 4 demonstrated that microhardness of the alloys was between 330 HV and 430 HV. It was close to dental Co-Cr alloys (350-390 HV). With the increase of Sn, the hardness showed an obviously ascending trend as a whole.

Along with increase of Sn, dispersed network phases α″ of the as-cast alloys precipitated ceaselessly, which might make the microhardness drop gently. But, solution strengthening of Sn was also enhanced gradually and improved the microhardness to a great extent. So, microhardness of the as-cast alloys increased gradually. After annealing, solution strengthening of Sn, as main factor, also improved the microhardness remarkably.

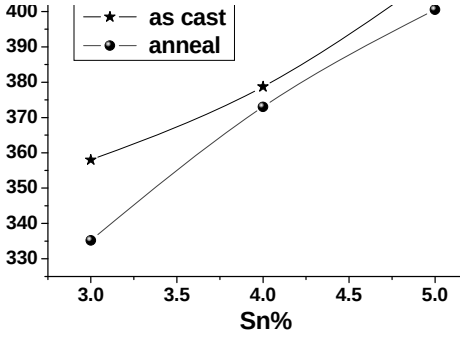

Fig. 4. Hardness (HV) of Ti-10Zr-5Mo-xSn alloys.

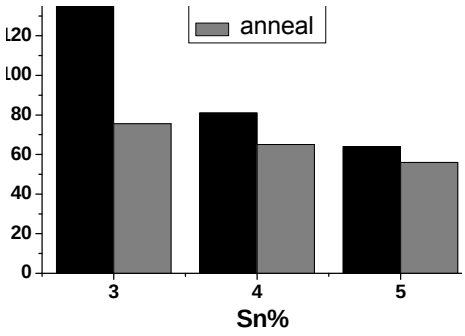

Fig. 5. Lost weight of Ti-10Zr-5Mo-xSn alloys in the abrasion.

3.4 Abrasion resistance

Fig. 5 showed the total worn loss weight of the alloys before and after annealing. It was clear loss weight of the alloys after annealing was lessened evidently. The total weight loss of the alloys decreased along with increase of Sn, too.

Fig. 6 showed optical micrographs of the worn surfaces of alloys after that they were worn with GCr15 grinding ring. The worn surface of 1# alloy (Fig. 6a, 6a′) presented obvious furrow phenomenon, and grinding marks generated significant plastic deformation. Moreover, a large number of massive abrasive dusts had comparatively obvious adhesion and accumulation phenomenon. The worn surface of 2# alloy (Fig. 6b, 6b′) also had obvious furrow phenomenon, but plastic deformation was not obvious. The worn surface of 3# alloy (Fig. 6c, 6c′) was smooth and glabrous, and furrow phenomenon was not obvious. Furthermore, exiguous abrasive dusts were distributed dispersedly, with a small quantity of accumulation.

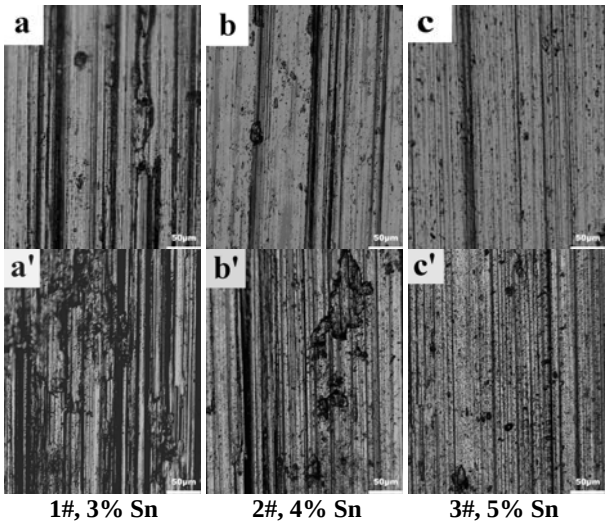

Fig. 6. Worn surfaces of Ti-10Zr-5Mo-xSn alloys (a,b,c, before annealing ; a',b',c', after annealing).

The abrasion resistance of the Ti alloys was involved in the hardness, strength, plasticity, etc. During the grinding process, when two frictional surfaces touched interactively, the superficial layer was prone to generate plastic deformation. It was generally believed that asymmetrical plastic deformation of each crystal grain would bring microcracks in the intergranular area. These microcracks grew and expanded along the grain boundary, along with ceaseless accumulating of the plastic deformation in the superficial layer. When microcracks expanded to the alloy surface, metal would fall off and form the abrasive dusts. Therefore , the accumulation of the plastic deformation , the budding and the expansion of microcracks were three stages in the formation of the abrasive dusts [11]. Simultaneously, most of abrasive dusts during the grinding process were prone to be conglutinated on the GCr15 grinding ring, which resulted in a mass of steel pits in the worn surfaces of the alloys. Through iterative mouthpiece pressing, the conglutinated abrasive dusts usually caused work-hardening, fatigue and oxidation, and finally formed dissociative abrasive dusts. During the last grinding process, dissociative abrasive dusts on the worn surface played plowing and brought furrows [11-12]. Therefore, the abrasion mechanisms of the alloys were sticking abrasion and abrasive particle abrasion.

Combining with hardness test results, as a result of lower hardness and better plasticity for 1# and 2# alloy, their worn surfaces were prone to generate plastic deformation. Furthermore, abrasive dusts were not easy to fall off and often conglutinated on the grinding ring, which played plowing during the grinding process. So, grinding cracks of 1# and 2# alloy were irregular greatly, and ravines were also quite deep. With increase of Sn, hardness of 3# alloy increased gradually, and plasticity lowered. Thus, grinding cracks were regular highly, and the worn surface was glabrous and smooth. Abrasive dusts distributed homogeneously, with a small quantity of accumulation. So, with increase of Sn, the abrasion resistance of alloys was improved remarkably.

Furthermore, it was obvious that loss weight of the alloys after annealing was lessened evidently, as shown in Fig. 5. According to the former phase and structure analysis, after annealing process, more lamellar β phases discontinuously were distributed between many needle-like or flaky α phases. Thereby, a large number of staggered flake or needle-like structures existed in the host or around the grain-boundary area. As a result, microcracks budding in the intergranular area, would encounter the more hindrances during the expansion process, and adjacent cracks could not connect one another, either. Therefore, it is only under the greater load that crystal grain could generate plastic deformation and that microcracks could bud and expand. In other words, the wearing capacity of the alloys after annealing was improved.

4. Conclusions

1. Ti-10Zr-5Mo-xSn alloys (x =3 , 4 , 5) was composed of α phase, βphase and a spot of α″ phase. Addition of Sn could accelerate α″ phase to appear. Furthermore, during the slow cooling process, Sn with β isomorphous element Mo could improve the stability of β phase and retain it up to room temperature. After the annealing, proportion of βphase increased.

2. With increase of Sn, hardness and abrasion resistance of the alloys were improved.

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